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RESEARCH MEMORANDUM

REVIEW OF SOME RECENT DATA ON BUFFET BOUNDARIES

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RESEARCH MEMORANDUM

REVIEW OF SOME RECENT DATA ON BUFFET BOUNDARIES

By Paul E. Purser and John A. Wyss

SUMMARY

A study has been made of a large amount of data pertaining to high-speed buffet boundaries of various airplane configurations. The data indicate a strong influence of wing configuration on buffet boundaries. Based on the comparisons available, reasonably accurate estimates of the buffet boundary can probably be made for unswept wings with thickness ratios above 8 to 10 percent. Accurate estimates can not yet be made for swept wings. Decreases in aspect ratio and thickness ratio and increases in sweepback tend to alleviate high-speed buffeting.

INTRODUCTION

During the past few years NACA studies of buffeting have been directed at several phases of the problem. These studies have included the following general programs:

1. Continual study, comparison, and correlation of all available data pertaining to buffeting

2. Wind-tunnel studies of shock-wave oscillations in the flow past airfoils and of pressure fluctuations on the surface and in the wakes of airfoils

3. Flight determination of the conditions under which buffeting occurs for various airplanes

4. Flight measurements of buffeting loads by means of accelerometers, strain gages, and pressure cells

As a part of the flight program some theoretical work is being done on vibratory phenomena and consideration is being given to the use of internal damping for alleviating buffeting loads.

The present paper is a review of data pertaining to buffet boundaries and as such includes at least parts of each of the previously

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listed four items or general programs. Much of the information on which this paper is based is contained in references 1 to 5.

DISCUSSION

General

The work under item 1 at both the Ames and Langley Laboratories of the NACA (references 1 and 2) has been directed toward trying to understand more about the basic causes and mechanism of high-speed buffeting. These studies have also been directed toward developing means of predicting the flight conditions of lift coefficient and Mach number in which one might expect buffeting to occur for various airplane configurations. Some of the progress that has been made toward these aims is discussed now.

Figure 1 shows a typical flight record of buffeting as indicated by an accelerometer mounted at the airplane center of gravity. Buffeting is evidenced by the oscillations appearing in the normal-acceleration trace. On this particular record the onset of buffeting is quite apparent. On other records the exact point for the beginning of buffeting is sometimes less apparent. However, investigations during the past few years have shown that buffeting which causes variations of ±0.03g to ±0.05g in acceleration at the airplane center of gravity are consistently detectable by NACA instrumentation. In general, pilots' opinions of the onset of buffeting have been found to correlate well with these instrument indications (reference 1).

Many frequencies appear in buffeting acceleration records; these frequencies usually can be traced to the natural frequencies of various structural components of the airplane, and quite often the dominant frequency appears to be that of the wing in primary bending. Also shown in figure 1 is a typical boundary of normal-force coefficient against Mach number which defines the flight conditions where buffeting will be experienced by a particular airplane. These boundaries are defined by plots, from many records, of the values of normal-force coefficient C_N and Mach number M corresponding to the points at which buffeting starts as indicated by the oscillating trace on the typical record. Along the steep portion of the boundary the buffeting is thought to be primarily due to compressibility rather than to reaching the stall as in the low Mach number portion of the boundary. The rest of this discussion is limited to the steep "compressibility" portion of the boundary - dealing first with normal-force coefficients near zero and then with the higher range of normal-force coefficients up to those approaching the stall.

Low-Lift Buffeting

Various investigations have disclosed several phenomena that are believed to result from shock-induced separation at high speeds. Among these are buffeting and wing dropping (lateral trim changes) in flight and changes in lift at a constant angle of attack near zero for symmetrical airfoil sections and wing models in wind tunnels. Since these phenomena seem to be allied, they all may be used along with schlieren and tuft observations of rough or separated flow to indicate the tendency of various configurations toward high-speed buffeting. To indicate the relationship of these various evidences of shock separation figure 2 has been prepared. This figure presents a plot of the Mach number at which shock separation was evidenced for airfoil sections and wings of various thickness ratios near zero lift. In this figure lines drawn at the appropriate thickness ratios are terminated by test points at the Mach number where evidences of flow separation occurred. Where the line is not terminated by a test point no zero-lift flow separation was evidenced up to the value of Mach number indicated by the end of the line. The test points indicate the type of flow-separation evidence; that is, changes in lift near zero angle of attack, low-lift buffeting, or low-lift wing dropping. The letters accompanying the symbols refer to the source of the data: airfoil sections and wing models in wind tunnels, rocket models, and airplanes. Boundaries have been drawn through the points representing airfoil-section data and finite-wing data to show the Mach numbers at or above which low-lift buffeting might be expected to occur. Obviously the scatter of test points in this figure indicates that the maximum wing thickness ratio is not suitable as a sole criterion of buffeting. However, the figure does indicate the alleviating effects of finite aspect ratio and low values of the wing thickness ratio on low-lift buffeting and other allied phenomena. The two lower lines in the figure, incidentally, represent two rocket-model configurations which have been flown several times up to Mach numbers of about 1.4 with no evidence of low-lift buffet.

Similar data are shown in figure 3 for swept wings to indicate the effects of sweep on low-lift buffet. The wings are divided into two groups - quarter-chord sweep angles of approximately 35° and approximately 45°. The 35° wings are, in order of decreasing thickness, the Douglas D-558-II airplane and rocket models, the North American F-86A airplanes, the Northrop X-4 airplane, and the Republic XF-91 airplane and rocket models. For wings with 45° quarter-chord sweep there are a research rocket model, the Consolidated Vultee XF-92A airplane and rocket models, and another research rocket. Although the data for swept wings are not sufficient to draw boundaries, comparison of figures 2 and 3 indicates an alleviating effect of sweep at constant streamwise thickness for all configurations shown except the X-4. The X-4, incidentally, has no horizontal tail; yet buffeting is present. This fact indicates that the lack of a horizontal tail is not necessarily an alleviating factor in buffeting.

High-Lift Buffeting

Figures 2 and 3 have indicated that the use of thin and/or swept wings can alleviate the low-lift high-speed buffet problem. Figure 4 shows similar trends toward alleviation at higher normal-force coefficients. The figure shows buffet boundaries for two airplanes and two rocket models (references 3 and 4). The Douglas D-558-II shows buffet down to practically zero lift; the data for the slightly thinner wing of the North American F-86 show a delay varying from 0.02 to 0.06 in Mach number as compared to the D-558-II, the test of the still thinner wing of the Republic XF-91 rocket model indicates a slightly higher boundary, and the very thin, nearly unswept wing rocket model was clear of buffet up to normal-force coefficients of about 0.7 at $M = 0.8$ and over 0.8 near $M = 1$. For the XF-91 model the test limit (imposed by longitudinal stability, control effectiveness, and control deflection range) ran from the highest point on the boundary, approximately parallel to the F-86 boundary up to $M = 0.9$, and then decreased smoothly to $C_N = 0.2$ at $M = 1.25$. For the other rocket model the test limit ran from the highest point on the boundary to $C_N = 0.5$ at $M = 1.3$.

Buffet Boundaries

As a result of part of the buffet research at the Ames Laboratory a procedure has been suggested for estimating the high-speed buffet boundaries for unswept wings of moderate to large thickness ratio. This procedure (reference 1) involves plotting the variation with normal-force coefficient of the lift-divergence Mach number from airfoil-section data for the airfoil corresponding to that at the maximum-thickness-ratio section of the wing. This boundary should be shifted to higher Mach numbers to account for the alleviating effects of finite aspect ratio. The amount of the Mach number shift can be taken as the difference at the appropriate thickness ratio between the two boundaries shown in figure 2 rather than as the value of $\Delta M = 0.06$ suggested in reference 1. This procedure has been used to estimate the high-speed buffet boundaries for the Bell X-1 and Grumman F8F-1 airplanes. Figure 5 shows the measured and estimated buffet boundaries for these airplanes. The agreement of estimates with measurements is excellent for the 18-percent-thick wing of the F8F-1 and for the 10-percent-thick wing of the X-1. For the 8-percent-thick wing of the X-1, however, flight tests did not show the shift in the boundary that might be expected.

The agreement shown is fairly representative of that found when buffet boundaries were estimated for nine other straight-wing airplanes having wing thickness ratios between 10 and 18 percent (reference 1 and unpublished comparisons).

Buffet boundaries have been estimated for swept-wing airplanes in two ways: first, by considering the streamwise airfoil sections and making no other allowance for sweep and, second, by considering airfoil sections normal to the swept reference line and correcting the boundaries in accordance with the simple cosine law. That is, in the second method, the estimated normal-flow Mach numbers were divided by the cosine of the sweep angle and the corresponding normal-force coefficients were multiplied by the square of the cosine. As shown in figure 6 conflicting results were obtained when these procedures were applied to the Douglas D-558-II and North American F-86A airplanes (reference 5). Use of the streamwise airfoil provided a good estimate for the D-558-II but neither procedure worked very well for the F-86. Consequently, as yet no procedure can be recommended for estimating the buffet boundaries for swept wings.

Buffet Intensity

The preceding discussion has dealt primarily with buffet boundaries as affected by wing configuration. However, the intensity of the buffeting when flying at values of C_N and M above the boundary is also of interest. Figure 7 presents contours of buffet intensity as measured by accelerometers located at the center of gravity for the Bell X-1 and Grumman F8F-1 airplanes. The buffet intensities have been expressed as normal-force coefficients rather than as acceleration increments. Admittedly these coefficients are somewhat fictitious since a complicated dynamic-response problem is involved, but they were used in order to account, at least approximately, for differences in wing loading, altitude, and dynamic pressure between various flights and various airplanes. The buffet boundaries have been assigned arbitrary intensities of $\Delta C_N \approx \pm 0.01$ since the previously noted threshold of $\pm 0.03g$ corresponds to values of ΔC_N of the order of 0.005 to 0.015 for the various airplanes and flight conditions considered. The difference in the rate at which buffet intensity increases with penetration past the boundary is quite marked for the Bell X-1 and Grumman F8F-1 airplanes. At least part of the much lower rate of increase in intensity for the X-1 quite probably can be attributed to the thinner wing on this airplane as compared with that of the F8F-1 although other differences such as structural response and damping undoubtedly affect the results to some degree. Some buffet-intensity data have been obtained on a

North American F-86A airplane (reference 3); these data are shown in figure 8. As in the case of the X-1, the intensity increases relatively slowly as the airplane penetrates beyond the boundary.

Also shown in figure 8 is the buffet boundary obtained for a later F-86A airplane. The boundary for the later airplane not only lies at about 0.04 higher Mach number but also indicates no buffeting below $C_N \approx 0.3$ up to $M = 1.0$. The boundaries for these two airplanes were both determined at the Ames Laboratory by using the same piloting techniques and instrumentation for both airplanes. Known differences between the airplanes are that no. 609 had a cable lock on the slats while on no. 291 the slats were held closed only by air loads. The looseness or free play in the slats (while on the ground) amounted to about ±1/16 inch horizontally and vertically for no. 291 and essentially zero horizontally and ±1/32 inch vertically for no. 609. Because the data were obtained on two different airplanes, it is questionable whether all the buffeting difference can be attributed to differences in the slats. It should be pointed out, however, that for airplane no. 291 the dominant frequency of 48 cycles per second appearing on the accelerometer records was equal to the natural frequency of slat shaking found in ground vibration tests. On airplane no. 609 there was no really dominant frequency in the records but the frequencies that were apparent varied from 38 to 48 cycles per second. The apparent tie-in between slat shaking and buffeting for these two airplanes may indicate that the buffeting noted is a different basic phenomenon for the F-86 than for the other airplanes for which buffet data are available.

CONCLUDING REMARKS

In conclusion, it is believed that the buffeting studies to date have indicated a strong influence of wing configuration on buffet boundaries and intensity. Based on the comparisons available, reasonably accurate estimates of the buffet boundary can probably be made for unswept wings with thickness ratios above 8 to 10 percent. Accurate estimates can not yet be made for swept wings. Decreases in aspect ratio and thickness ratio and increases in sweepback tend to alleviate high-speed buffeting.

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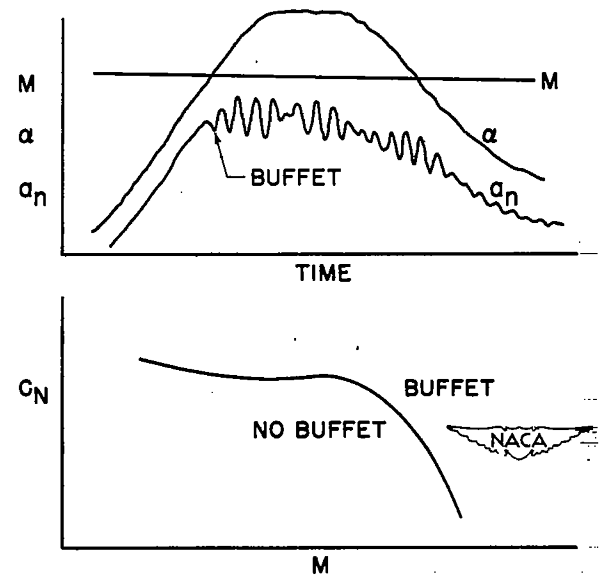

Figure 1.- Typical flight buffet record and buffet boundary derived from such records.

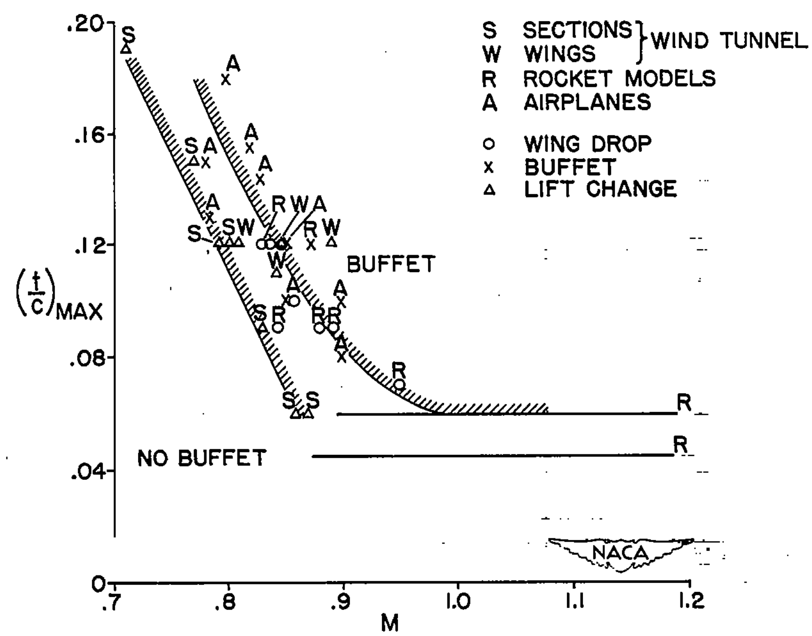

Figure 2.- Effect of airfoil thickness on Mach number at which evidences of zero-lift flow separation occur for airfoil sections and unswept wings.

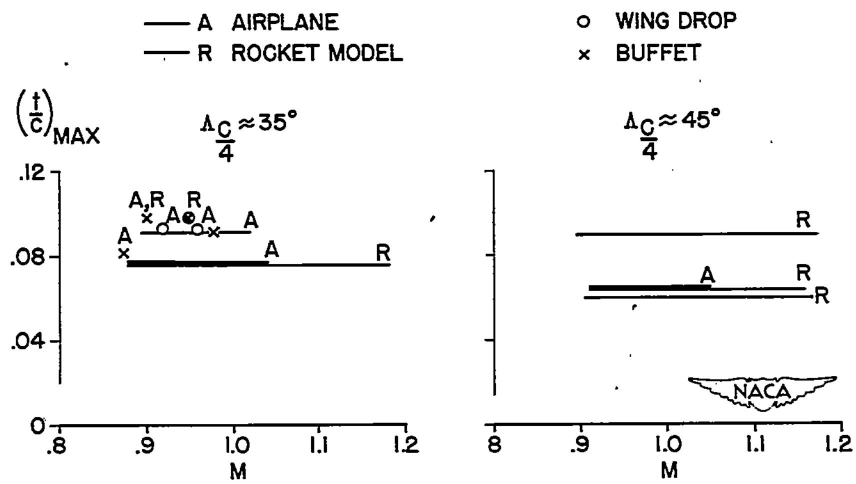

Figure 3.- Effect of airfoil thickness on Mach number at which evidences of zero-lift flow separation occur for swept wings.

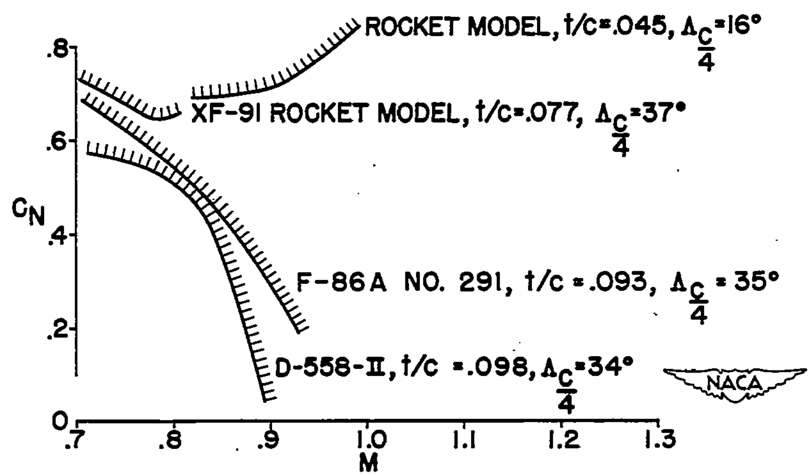

Figure 4.- Buffet boundaries for configurations which did and did not exhibit low-lift buffeting.

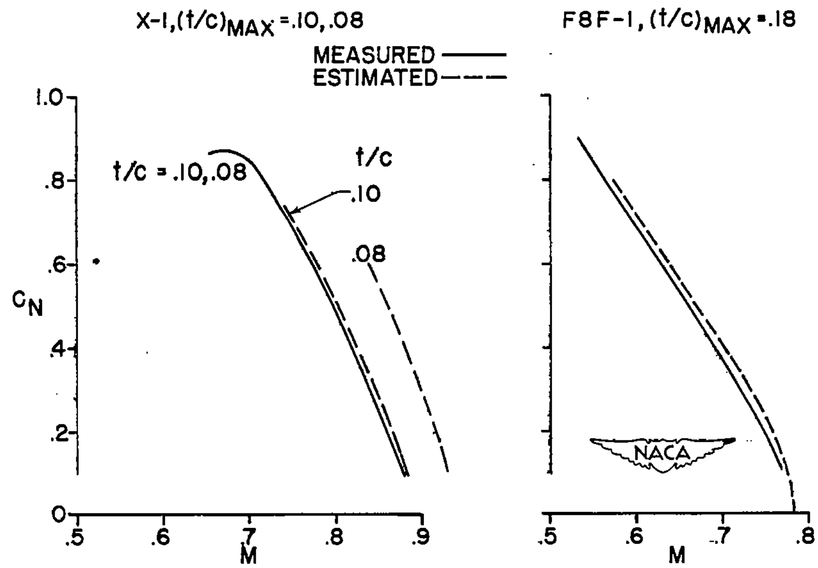

Figure 5.- Comparison of measured and estimated buffet boundaries for unswept wings.

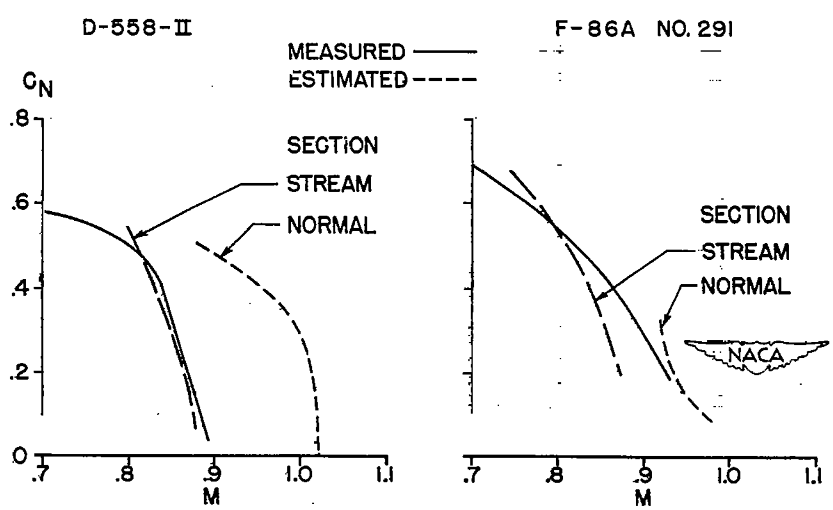

Figure 6.- Comparison of measured and estimated buffet boundaries for swept wings.

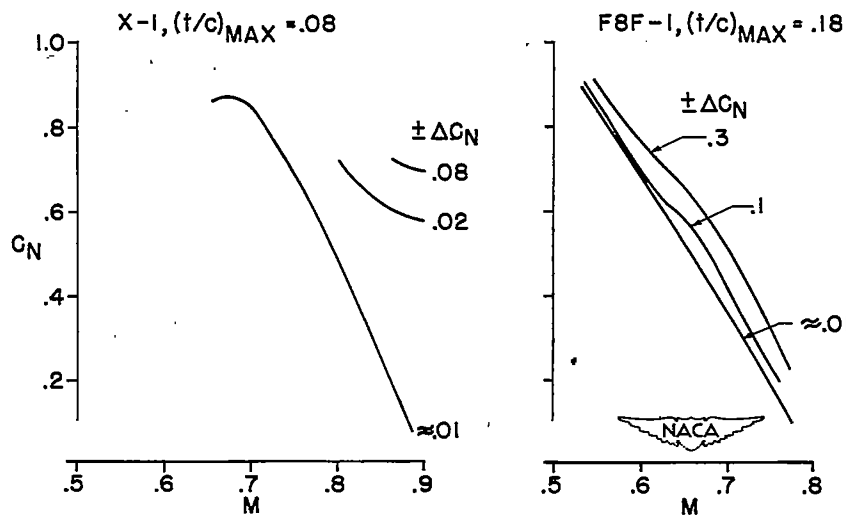

Figure 7.- Buffet intensity as measured by accelerometers at the center of gravity for two unswept-wing airplanes.

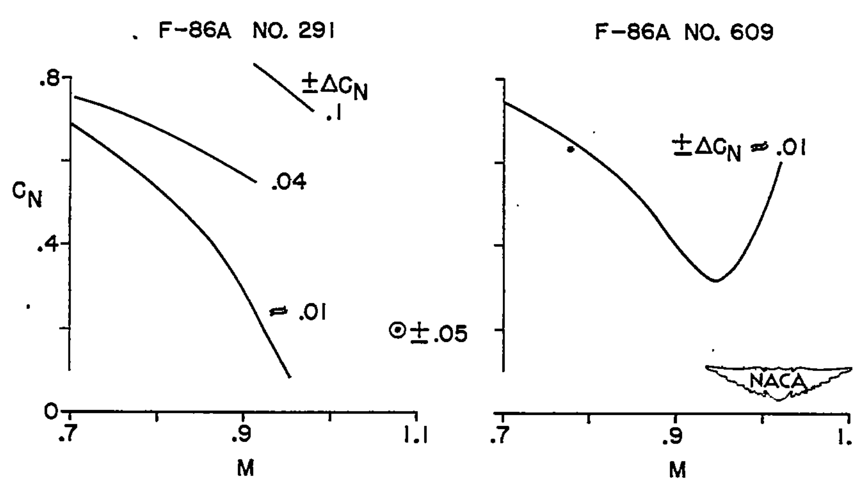

Figure 8.- Buffet intensity as measured by accelerometers at the center of gravity for two swept-wing airplanes.